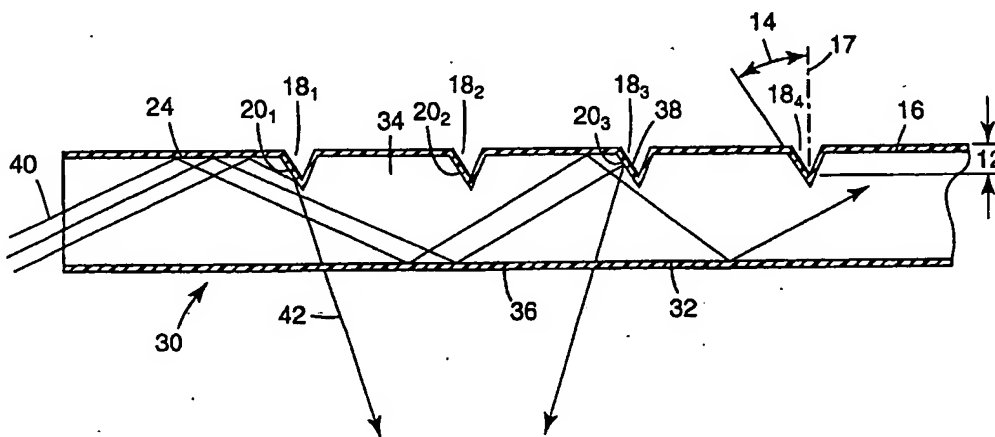


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## (57) Abstract

An illumination device produces a desired illumination pattern by tailoring the configuration of individual light extraction structures. At least two of the light extraction structures have different configurations from one another. The illumination device includes a light guide having a light guide core and an optically smooth surface for propagating light through the core. A light emitting region extends along a portion of the core and includes a plurality of light extraction structures distributed along the optically smooth surface. The light extraction structures are configured so that light reflected therefrom is emitted from the light guide through the optically smooth surface.

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## ILLUMINATION DEVICE FOR PRODUCING PREDETERMINED INTENSITY PATTERNS

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### BACKGROUND OF THE INVENTION

The present invention relates generally to an illumination device, and more particularly, to a light guide illumination device in which light extraction structures are configured to produce a predetermined intensity pattern such as for use in a vehicle.

10       Optically transmissive materials, such as glass or polymers may be used as light guides to propagate light. A light guide typically includes at least one surface adapted to receive light from a light source and an optically smooth surface for reflecting light propagating through or along the light guide. Common examples of light guides include optical fibers traditionally used in the data communication industry and more recently light  
15       fibers used for illumination purposes. For example, U.S. Patent No. 5,432,876 (the '876 patent) discloses one such illumination device employing light fibers. In this device, light may be injected into at least one end of a light fiber and allowed to exit the fiber at a predetermined position or positions along the length of the fiber to produce an even illumination pattern. Light extraction structures or notches are formed in the core of the  
20       light fiber. The extraction structures define first and second reflecting surfaces, which reflect in a radial direction a portion of the light propagating axially through the fiber. The reflected light is directed at an angle that is less than the critical angle necessary for continued propagation along the fiber according to the principle of total internal reflection. As a result, the reflected light is extracted from the fiber. In contrast to prior techniques  
25       such as subjecting the fiber to relatively sharp bends, this system extracts light from the fiber in a controlled fashion.

      Light fiber illumination devices have been proposed for use in automobiles and other vehicles. For example, they can be used to evenly distribute a point light source into a long, narrow line that may be employed in spoilers, along the edges of rear windows, or  
30       to follow the curve of a trunk lid. Examples of such devices may be found, for example, in U.S. Patent Nos. 5,222,794, 4,811,172, 4,868,718, and 4,949,227.

Light fiber illumination devices can also be used as side markers, emergency flashers, and center high mounted stop lamps, which can serve as indicators of a vehicle's features such as its overall length, width, and height. These devices often must meet specified standard requirements. For example, the Society of Automotive Engineers (SAE) sets forth a variety of different standards that recommend performance requirements for vehicle illumination devices, which define the amount, direction and distribution of light that the device should produce. For example, certain devices are required to provide light output over an angular range as large as +/- 45 degrees for minimum vehicle conspicuity.

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### SUMMARY OF THE INVENTION

The above requirements are often difficult or impossible to achieve with known light fiber illumination devices because they produce a limited set of intensity distributions which do not generally conform with any particular prescribed standard (*i.e.*, SAE, etc.). This limitation arises because devices known in the art comprise light extraction structures that vary only in spacing and depth.

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The present invention is therefore directed to the problem of providing an illumination device with light extraction structures that are appropriately configured to produce a predetermined illumination pattern, for example, one that may be uniform over a range of angles or that has a peak intensity at a given angle.

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The present invention solves this problem by providing a light guide illumination device that has differently configured light extraction structures. A desired illumination pattern is achieved by individually tailoring the notch angle of each light extraction structure.

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The present invention provides an illumination device that includes a light guide having a light guide core and an optically smooth surface for propagating light through the core. A light emitting region extends along a portion of the core and includes a plurality of light extraction structures distributed along the optically smooth surface. The light extraction structures are configured so that light reflected therefrom is emitted from the light guide through the optically smooth surface. At least two of the light extraction structures have different configurations from one another.

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In one aspect of the invention, each light extraction structure includes an optically reflective surface extending into the light guide core and oriented at a notch angle to

reflect light at an angle less than a critical angle so that light is emitted from the light guide through the optically smooth surface. The notch angle denotes the angle between the optically reflective surface and the axis perpendicular to the optically smooth surface.

In another aspect of the invention, the different configurations of the light  
5 extraction structures correspond to different notch angles.

In accordance with yet another aspect of the invention, the light guide may be a light fiber. Additionally, the light guide may have a circular or noncircular cross-sectional shape, and may even be a planar waveguide.

In accordance with another aspect of the invention, the plurality of light extraction  
10 structures have different configurations selected so that the emitted light forms a prescribed illumination pattern. The prescribed illumination pattern may be, for example, substantially uniform over an angular distribution of +/- 45 degrees, or may be substantially non-uniform by providing relatively more intense light over an angular distribution of no more than about +/- 10 degrees. "Angular distribution" is defined in  
15 relation to an essentially linear illumination device such as a light fiber, and means the distribution of light rays as a function of angle to some fixed direction. In the present case, light is emitted opposite from the side in which light extraction structures are formed, and this is defined as the direction of zero angle. Furthermore, this invention is primarily concerned with the angular distribution in the plane that contains the zero angle direction  
20 as well as the fiber axis. In addition to providing an illumination source that has pre-defined intensity levels when viewed by an observer, the prescribed illumination pattern may illuminate a target in a uniform or non-uniform manner. Therefore, available light is distributed efficiently to a target or to satisfy a prescribed standard. When employed as a vehicular illumination device, the prescribed illumination pattern may conform to an  
25 established standard for a vehicular illumination device.

In accordance with another aspect, the plurality of light extraction structures may be equally spaced apart from one another along the optically smooth surface.

Alternatively, the plurality of light extraction structures may be unequally spaced apart from one another along the optically smooth surface.

30 In accordance with another aspect, the plurality of light extraction structures may be distributed along a plurality of longitudinal axes of a light guide. Preferably, a light guide in the form of a light fiber having two longitudinal axes may have light extraction

structures having unequal notch angles and/or uneven notch spacing distributed along the axes.

In one particularly advantageous embodiment, the light guide is formed from a polymerizable material such as an acrylate, silicone, or urethane material.

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### BRIEF DESCRIPTION OF THE DRAWING

**FIG. 1** is a schematic, cross-sectional view of a known illumination device illustrating the operation of the light extraction structures.

**FIG. 2** is a perspective view of the light guide shown in **FIG. 1**.

10 **FIG. 3** is a schematic, plan view of an illumination device constructed in accordance with the present invention.

**FIG. 4** shows the illumination pattern produced by the illumination device shown in **FIG. 3**.

15 **FIG. 5** shows the intensity distribution in the horizontal direction produced by the illumination device shown in **FIG. 3**.

**FIG. 6** shows the illumination pattern produced by another embodiment of the inventive illumination device.

**FIG. 7** shows the intensity distribution in the horizontal direction produced by the illumination device employed in **FIG. 6**.

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### DETAILED DESCRIPTION

#### Light Guide Illumination Device

**FIG. 1** depicts a side view of a portion of a known illumination device. The illumination device is formed from a light guide 30 having a circumferential surface 16 that includes one or more light extraction structures 18<sub>1</sub>, 18<sub>2</sub>, 18<sub>3</sub>, ... formed therein. Typically, light guide 30 further comprises core 34 having a surrounding cladding 36. Each extraction structure includes at least one optically smooth surface 20<sub>1</sub>, 20<sub>2</sub>, 20<sub>3</sub>, ... In operation, light ray 40 strikes a portion 24 of circumferential surface 16 not occupied by a light extraction structure 18, where it is reflected back into the light guide at an angle greater than the critical angle of the light guide, and accordingly, continues to propagate along the fiber. By contrast, light ray 42 strikes an optically smooth surface 20<sub>1</sub> of light extraction structure 18<sub>1</sub>, which reflects light ray 42 into light guide 30 at an angle which is

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less than the critical angle necessary for continued propagation along light guide 30. Light ray 42 is thereby transmitted through opposite surface 32 of light guide 30 at a position opposed to the location of extraction structures 18. In one exemplary embodiment of the present invention, cladding 36 covering optically smooth surfaces 20<sub>1</sub>, 20<sub>2</sub>, 20<sub>3</sub>, ... is coated with reflective material 38 such as aluminum or silver, for example, to reflect light of less than the critical angle that may be otherwise lost through surfaces 20<sub>1</sub>, 20<sub>2</sub>, 20<sub>3</sub>, ...

The configuration of light extraction structures 18 may be characterized in terms of their depth 12 into light guide 30 and notch angle 14 formed between surface 20 and axis 17 normal to surface 16. Notch angle 14 determines the direction of the light transmitted through surface 32 of light guide 30. Known light guide illumination devices employ light extraction structures having uniform notch angles. However, this arrangement limits the variations in the illumination pattern that the devices can produce.

The present invention overcomes the limitations of known illumination devices by providing a series of light extraction structures with different notch angles. That is, in the present invention, the angles 14 of light extraction structures 18 are not all the same. Rather, in accordance with the present invention, the notch angles are individually tailored for each extraction structure so that the illumination device provides the desired illumination pattern by integrating the light from different light extraction structures.

FIG. 2 shows a perspective view of the light guide illumination device shown in FIG. 1. For purposes of discussion, the longitudinal axis of light guide 30 will be defined as extending in the horizontal or x direction. Therefore, angular distribution of light, as defined above, is measured in the +/- x direction. The y direction will be defined as the vertical direction, which denotes points above and below the illumination device.

Therefore, radial distribution of light is measured in the +/- y direction. The z direction, therefore, defines the direction in which light is emitted and the luminous intensity of the device is measured as a function of an angle from the z direction, in the x-z plane, as depicted by trace 50 of FIG. 2. Thus, the illumination device will emit light so that it forms an illumination pattern in the x-z plane.

As previously mentioned, vehicular illumination devices must often meet standards that set forth stringent specifications for the illumination pattern that they produce. For example, some devices are required to produce an illumination pattern in the x-z plane that is relatively narrowly confined in the vertical (y) direction but which provides roughly

uniform intensity in the horizontal (x) direction. For example, one particular illumination device, which is employed as a vehicle side marker, requires that the intensity of the light in the horizontal direction should be roughly uniform over +/- 45 degrees. An illumination device having a series of uniformly configured light extraction structures will not yield  
5 such an intensity pattern. However, the present invention discloses that many different intensity patterns may be produced by providing a series of light extraction structures that have different configurations. Specifically, the invention teaches that by providing a plurality of light extraction structures having several different notch angles the intensity pattern can be tailored for a given application. That is, in the present invention the notch  
10 angle now becomes an adjustable parameter that can be varied to produce desired illumination patterns. For example, **FIG. 3** shows an embodiment of the present invention that yields the requisite intensity pattern for the previously mentioned vehicle side marker.

While the particular embodiments of the invention shown in **FIG. 3** and described below are formed from a light fiber, it should be recognized that the present invention is  
15 not limited to light fibers but rather is applicable to any form of light guide. Moreover, the light guides need not have a circular cross-section, but rather may have any desired shape. For example, in some embodiments the present invention contemplates the use of planar waveguides.



The illumination device shown in FIG. 3 employs a light fiber 40 that is 100 mm in length on which twenty light extraction structures 48<sub>1</sub>, 48<sub>2</sub>, 48<sub>3</sub>, ... 48<sub>20</sub> are disposed. The diameter of light fiber 40 is 7 mm. Six differently configured light extraction structures are employed, which extend along the light fiber in a given sequence that is repeated in full three times. As tabulated in Table 1, the notch angles  $\theta_1, \theta_2, \theta_3, \dots, \theta_{20}$  formed between the surface 20 and the normal direction 17 for extraction structures 48<sub>1</sub>, 48<sub>2</sub>, 48<sub>3</sub>, 48<sub>4</sub>, 48<sub>5</sub>, 48<sub>6</sub>, are, respectively, 36, 68, 40, 56, 47.5, and 63 degrees. Extraction structures 48 are uniform in depth. The center of the first light extraction structure 48<sub>1</sub> is located 50 mm from the input end 45 of light fiber 40. The remaining light extraction structures are unevenly spaced apart from one another. Table 1 also shows the location of the center of each extraction structure as measured from the first notch of light fiber 40.

TABLE 1

Light Extraction Structure	Position From First Notch (mm)	Notch Angle ( $\theta$ ) (degrees)
48 <sub>1</sub>	0.000	36
48 <sub>2</sub>	6.610	68
48 <sub>3</sub>	12.964	40
48 <sub>4</sub>	19.077	56
48 <sub>5</sub>	24.966	47.5
48 <sub>6</sub>	30.647	63
48 <sub>7</sub>	36.134	36
48 <sub>8</sub>	41.441	68
48 <sub>9</sub>	46.584	40
48 <sub>10</sub>	51.575	56
48 <sub>11</sub>	56.427	47.5
48 <sub>12</sub>	61.153	63
48 <sub>13</sub>	65.767	36
48 <sub>14</sub>	70.279	68
48 <sub>15</sub>	74.701	40
48 <sub>16</sub>	79.046	56
48 <sub>17</sub>	83.325	47.5
48 <sub>18</sub>	87.548	63
48 <sub>19</sub>	91.728	36
48 <sub>20</sub>	95.875	68

A reflector 43 may be incorporated at the end of light fiber 40 that is remote from the light source. Any light that is not emitted by one of the light extraction structures 48 upon its initial pass through the light fiber will be reflected so that it has another opportunity to be emitted by a light extraction structure 48. In this way a greater portion of the total light directed into light fiber 40 is used for illumination purposes.

FIG. 4 shows the illumination pattern produced in the x and y directions by the illumination device shown in FIG. 3. FIG. 5 shows a graph of the light intensity vs. angle to the z direction (in the x-z plane) produced by the same device. As FIG. 5 indicates, the intensity is roughly uniform over an angular range of about  $\pm 45$  degrees. In the y (or vertical) direction, the intensity is concentrated within an angular range of about  $\pm 15$  degrees.

Another embodiment of the present invention may be used as an emergency flasher for a vehicle. The intensity pattern for the emergency flasher as set forth by the Society of Automotive Engineers should be narrowly focused in the y (or vertical) direction with a peak intensity that extends over a relatively narrow angle in the x (or horizontal) direction. The emergency flasher employs a light fiber that is 400 mm in length and 6.35 mm in diameter on which 200 light extraction structures are disposed. Four differently configured light extraction structures are employed. Table 2 shows the notch angles formed between the surface of the light guide and the normal direction for each of the extraction structures. The extraction structures are uniform in depth. Table 2 also shows the location of the center of each extraction structure as measured from the first notch of light fiber referred to in Example 2 as notch 0. As in the previously discussed embodiment of the invention, a reflector may be incorporated at one end of light fiber so that a greater fraction of the light directed into the light fiber appears in the resulting illumination pattern.

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Table 2.

Notch No.	Distance from 1" notch, mm	Notch angle, deg.	Notch No.	Distance from 1" notch, mm	Notch angle, deg.	Notch No.	Distance from 1" notch, mm	Notch angle, deg.	Notch No.	Distance from 1" notch, mm	Notch angle, deg.	Notch No.	Distance from 1" notch, mm	Notch angle, deg.
0	0.000	49	50	157.387	49	100	262.928	49	150	338.559	49			
1	3.844	55	51	159.919	55	101	264.674	55	151	339.882	55			
2	7.655	36	52	162.430	36	102	266.408	36	152	341.199	36			
3	11.433	49	53	164.922	49	103	268.130	49	153	342.510	49			
4	15.179	55	54	167.393	55	104	269.841	55	154	343.816	55			
5	18.893	49	55	169.845	49	105	271.541	49	155	345.117	49			
6	22.576	55	56	172.278	55	106	273.230	55	156	346.414	55			
7	26.226	45	57	174.692	45	107	274.908	45	157	347.705	45			
8	29.846	49	58	177.087	49	108	276.575	49	158	348.991	49			
9	33.435	55	59	179.462	55	109	278.232	55	159	350.273	55			
10	36.994	49	60	181.820	49	110	279.878	49	160	351.549	49			
11	40.522	55	61	184.159	55	111	281.514	55	161	352.822	55			
12	44.020	36	62	186.479	36	112	283.139	36	162	354.090	36			
13	47.489	49	63	188.782	49	113	284.754	49	163	355.354	49			
14	50.928	55	64	191.067	55	114	286.360	55	164	356.613	55			
15	54.338	49	65	193.334	49	115	287.955	49	165	357.868	49			
16	57.720	55	66	195.584	55	116	289.541	55	166	359.120	55			
17	61.072	45	67	197.816	45	117	291.117	45	167	360.367	45			
18	64.397	49	68	200.032	49	118	292.684	49	168	361.611	49			
19	67.694	55	69	202.230	55	119	294.241	55	169	362.851	55			
20	70.962	49	70	204.412	49	120	295.790	49	170	364.087	49			
21	74.204	55	71	206.577	55	121	297.329	55	171	365.320	55			
22	77.418	36	72	208.726	36	122	298.859	36	172	366.550	36			
23	80.605	49	73	210.859	49	123	300.380	49	173	367.776	49			
24	83.766	55	74	212.975	55	124	301.893	55	174	368.999	55			

Notch No.	Distance from 1 <sup>st</sup> notch, mm	Notch angle, deg.	Notch No.	Distance from 1 <sup>st</sup> notch, mm	Notch angle, deg.	Notch No.	Distance from 1 <sup>st</sup> notch, mm	Notch angle, deg.	Notch No.	Distance from 1 <sup>st</sup> notch, mm	Notch angle, deg.	Notch No.	Distance from 1 <sup>st</sup> notch, mm	Notch angle, deg.
25	86.900	49	75	215.076	49	125	303.397	49	175	370.219	49			
26	90.008	55	76	217.161	55	126	304.893	55	176	371.436	55			
27	93.090	45	77	219.231	45	127	306.380	45	177	372.650	45			
28	96.147	49	78	221.285	49	128	307.859	49	178	373.861	49			
29	99.178	55	79	223.325	55	129	309.330	55	179	375.070	55			
30	102.184	49	80	225.349	49	130	310.793	49	180	376.276	49			
31	105.165	55	81	227.358	55	131	312.248	55	181	377.479	55			
32	108.122	36	82	229.353	36	132	313.696	36	182	378.680	36			
33	111.054	49	83	231.333	49	133	315.135	49	183	379.879	49			
34	113.961	55	84	233.299	55	134	316.568	55	184	381.075	55			
35	116.845	49	85	235.250	49	135	317.993	49	185	382.270	49			
36	119.705	55	86	237.188	55	136	319.410	55	186	383.462	55			
37	122.542	45	87	239.112	45	137	320.821	45	187	384.653	45			
38	125.356	49	88	241.022	49	138	322.224	49	188	385.842	49			
39	128.146	55	89	242.918	55	139	323.621	55	189	387.029	55			
40	130.914	49	90	244.801	49	140	325.011	49	190	388.214	49			
41	133.659	55	91	246.671	55	141	326.394	55	191	389.398	55			
42	136.382	36	92	248.528	36	142	327.770	36	192	390.580	36			
43	139.083	49	93	250.371	49	143	329.140	49	193	391.761	49			
44	141.761	55	94	252.202	55	144	330.504	55	194	392.941	55			
45	144.419	49	95	254.021	49	145	331.862	49	195	394.120	49			
46	147.054	55	96	255.827	55	146	333.213	55	196	395.298	55			
47	149.669	45	97	257.620	45	147	334.558	45	197	396.474	45			
48	152.262	49	98	259.401	49	148	335.898	49	198	397.650	49			
49	154.835	55	99	261.171	55	149	337.231	55	199	398.825	55			

FIG. 6 shows the illumination pattern produced in the x-y plane by the previously mentioned emergency flasher. FIG. 7 shows a graph of the light intensity vs. angle to the z direction (in the x-z plane) produced by the same device. As FIG. 7 indicates, the peak  
5 intensity in the horizontal direction is roughly limited to an angular range of about +/- 10 degrees. Advantageously, in the present design, horizontal light distribution extends out to +/-60 degrees, providing added conspicuity of the device.

In general, the illumination device of the present invention encompasses any light guide that has at least two differently configured light extraction structures so that  
10 overlapping light rays are integrated together to produce a given illumination pattern. The particular configuration of light extraction structures as well as their arrangement on the light guide will depend on the illumination pattern that is desired. The illumination pattern will in turn generally depend on the application for which the illumination device is to be used. While the configuration and arrangement of the light extraction structures may be  
15 empirically determined for any given illumination pattern, the following guidelines may prove helpful in this process.

Light is reflected from any given notch surface in a lobe or cone whose intensity and set of ray angles is determined by the notch angle (*e.g.*, angle 17 in FIG. 1). Lobes of light reflected from adjacent notch surfaces can overlap to some extent and are essentially  
20 additive when they overlap. The ray angle distribution from each notch surface contributes to the aggregate far field output results from the illumination device. The design of specific set of notch angles and spacings of an illumination device allows for tailoring of far field output. By 'far field' is meant a distance from the light source of greater than 20 times the size, *i.e.*, length, of the light source.

As previously mentioned, the arrangement of the light extraction structures along the light guide will also be dictated by the desired illumination pattern. For example, the spacing between adjacent light extraction structures need not be constant, but may vary along the light guide. In addition, a series of light extraction structures defined by a particular sequence of notch angles may be repeated one or more times along the light  
30 guide. Finally, the light extraction structures can be varied in their depth into the light guide, as described in U. S. Patent No. 5,432,876, incorporated herein by reference. Variations in notch depth can produce variations in radial (+/- y) distribution of emitted

light. Light extraction structures of the present invention may be distributed along a single longitudinal axis of the light emitting region of the light guide, or they may be distributed along more than one longitudinal axis. Light guides having at least two sets of light extraction structures distributed along at least two longitudinal axes of a light guide are  
5 described in U. S. Patent No. 5,845,038, incorporated herein by reference.

### **Light Guide Illumination Device Fabrication**

The illumination device of the present invention may be fabricated by any desired technique. In one method the light extraction structures are directly micro-machined into  
10 the light guide itself. In another method, a molding process is employed, which uses a conventional mold such as a two piece mold. Alternatively, the mold may be an expandable mold of the type disclosed in U.S. Application Serial No. 09/026,836, entitled "Method and Apparatus for Seamless Microreplication Using an Expandable Mold." Briefly, an expandable mold is formed from a flexible material having a generally hollow  
15 portion that corresponds to the shape of the desired finished article (i.e., the light guide). The hollow portion is accessible through at least one opening. The hollow portion is filled with a curable material that hardens in the shape of the hollow portion of the mold. Once hardened, the finished article is removed by applying a pressure differential between the inside and outside of the mold so that the walls of the mold distend to facilitate removal of  
20 the molded article. Additional details concerning the expandable mold may be found in the previously mentioned patent application, which is hereby incorporated by reference in its entirety including the drawings, as if repeated herein.

Regardless of the type of mold that is employed, the curable material that forms the finished article may be any material that hardens into a substantially optically transparent  
25 material and which can be introduced into the mold and hardened at temperatures and/or pressure conditions that do adversely affect the mold. The curable material may be curable by heat, radiation, or other known processes. Suitable curable materials include a polymerizable compound or mixture. Acrylates are a class of curable materials that are preferable for their transparency properties. Urethanes are also a desirable class of curable  
30 materials because their contraction during curing tends to be minimal, although only certain formulations have desirable transparency properties. Yet another curable material that may be used is silicone.

Other techniques also may be used to fabricate the illumination device of the present invention. For example, U.S. Patent No. 5,631,994 is directed to a method in which an overlay is provided that incorporates the extraction structures. The overlay, which is formed from an optically transparent substrate, is fabricated by conventional manufacturing processes, such as a molding process. An adhesive backing is applied to the overlay so that it can adhere to the fiber core.

Although various embodiments are specifically illustrated and described herein, it will be appreciated that modifications and variations of the present invention are covered by the above teachings and within the purview of the appended claims without departing from the spirit and intended scope of the invention. For example, while the present invention has been described as being particularly applicable to vehicular illumination devices, one of ordinary skill in the art will recognize that the invention is equally applicable in many other situations where task lighting is required. In particular, the present invention may be used to provide a prescribed illumination pattern that is required by any of the numerous organizations that establish illumination standards.

## CLAIMS:

1. An illumination device comprising:  
a light guide including a light guide core having an optically smooth  
5 surface for propagating light therethrough and a light emitting region extending along a  
portion of the core, the core including a plurality of light extraction structures extending  
along the core, said light extraction structures being configured so that light reflected  
therefrom is emitted from the light guide through the optically smooth surface;  
characterized in that at least two of the light extraction structures have different  
10 configurations from one another.
2. An illumination device according to claim 1, further characterized in that at  
least two of the light extraction structures include an optically reflective surface extending  
into the light guide core and oriented to reflect light at an angle less than a critical angle so  
15 that light is emitted from the light guide through the optically smooth surface, said at least  
two optically reflective surfaces forming different angles with respect to an axis  
perpendicular to the optically smooth surface.
3. An illumination device according to any preceding claim, further  
20 characterized in that each light extraction structure includes an optically reflective surface  
extending into the light guide core and oriented at a notch angle to reflect light at an angle  
less than a critical angle so that light is emitted from the light guide through the optically  
smooth surface, said notch angle denoting the angle between the optically reflective  
surface and the axis perpendicular to the optically smooth surface  
25
4. An illumination device according to claim 3, further characterized in that  
said different configurations correspond to different notch angles.
5. An illumination device according to any preceding claim, further  
30 characterized in that said light guide comprises a light fiber.



6. An illumination device according to any preceding claim, further characterized in that said light guide has a circular cross-sectional shape.

7. An illumination device according to any of claims 1 to 4, further  
5 characterized in that said light guide comprises a planar light guide.

8. An illumination device according to any preceding claim, further characterized in that the light extraction structures have a notch angle denoting the angle between an optically reflective surface of the light extraction structure and an axis  
10 perpendicular to the optically smooth surface, and wherein the light extraction structures include a series of light extraction structures defined by a particular sequence of notch angles, said series of light extraction structures being repeated a prescribed number of times along the optically smooth surface of the core.

9. An illumination device according to any preceding claim, further  
15 characterized in that the light extraction structures have different configurations selected so that the emitted light forms a prescribed illumination pattern.

10. An illumination device according to claim 9, further characterized in that  
20 the light extraction structures are arranged so that the prescribed illumination pattern conforms to a prescribed illumination requirement.

11. An illumination device according to claim 10, further characterized in that  
25 the prescribed illumination requirement is an established standard for a vehicular illumination device.

12. An illumination device according to any preceding claim, further characterized in that the light extraction structures are equally spaced apart from one another along the core.

30

13. An illumination device according to any of claims 1 to 12, further characterized in that the light extraction structures are unequally spaced apart from one another along the core.

5 14. An illumination device according to any preceding claim, further characterized in that the core is formed from a polymerizable material.

15 15. An illumination device according to claim 14, further characterized in that the polymerizable material is selected from the group consisting of acrylate, urethane, and silicone materials.

16 16. An illumination device according to any preceding claim, further characterized in that a reflector is disposed at one end of the light guide for reflecting light back into the core.

15 17. An illumination device according to any preceding claim, further characterized in that the device is part of an automobile or other vehicle.

20 18. A method for generating a prescribed illumination pattern, said method comprising propagating light through an illumination device that includes a light guide core having an optically smooth surface and a light emitting region extending along a portion of the core, the light emitting region including a plurality of light extraction structures distributed along the optically smooth surface of the light guide core, characterized in that the device is an illumination device according to any preceding claim,  
25 and in that the angles formed between the optically reflective surfaces and an axis perpendicular to the optically smooth surface are arranged so that light is emitted through the optically smooth surface in the prescribed illumination pattern.

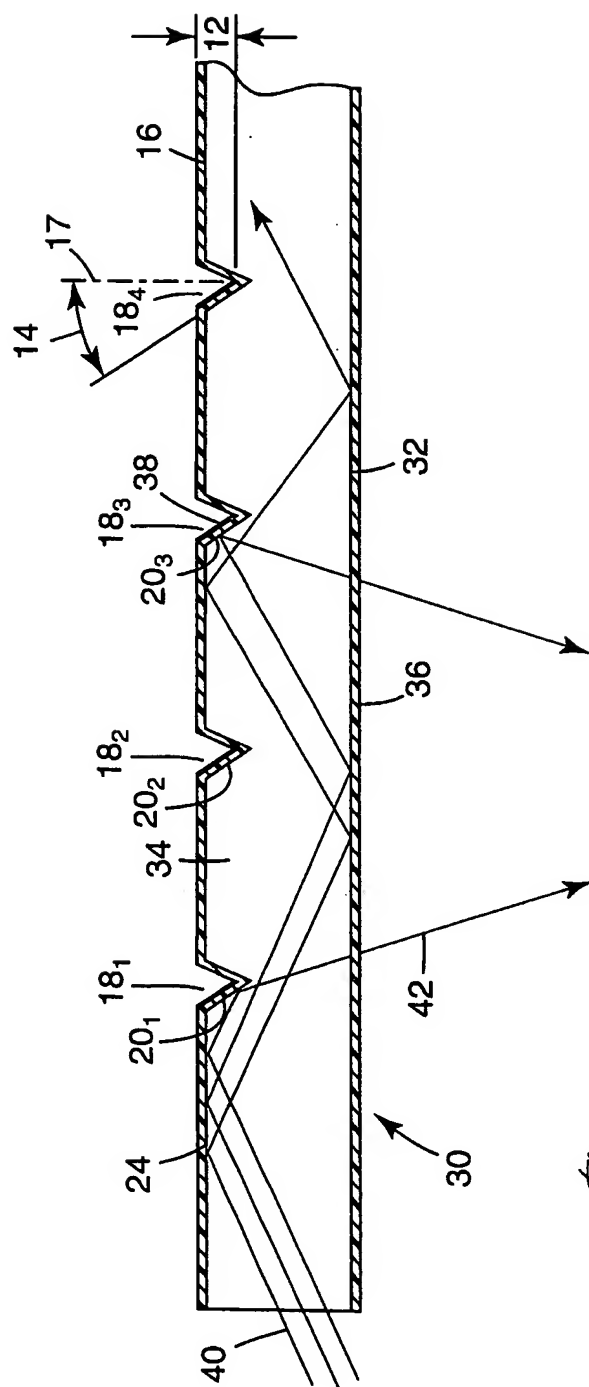
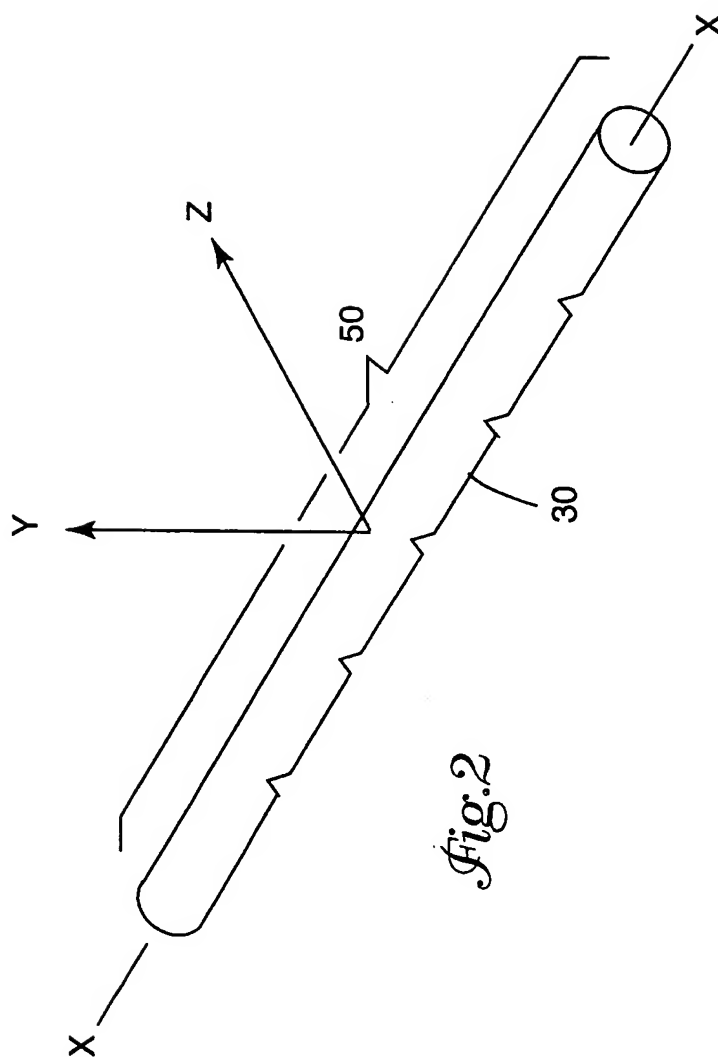
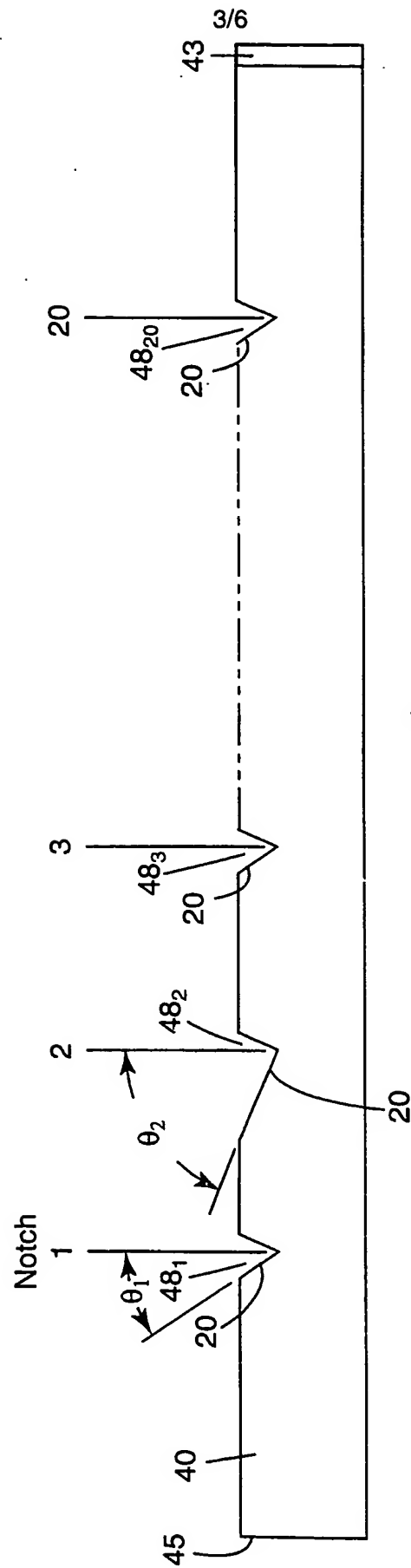
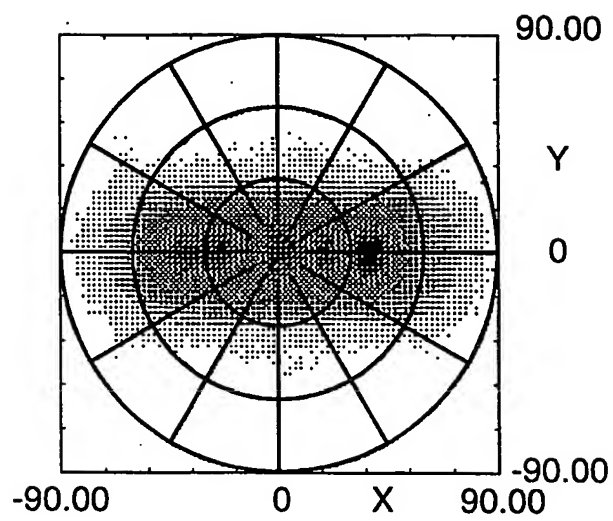
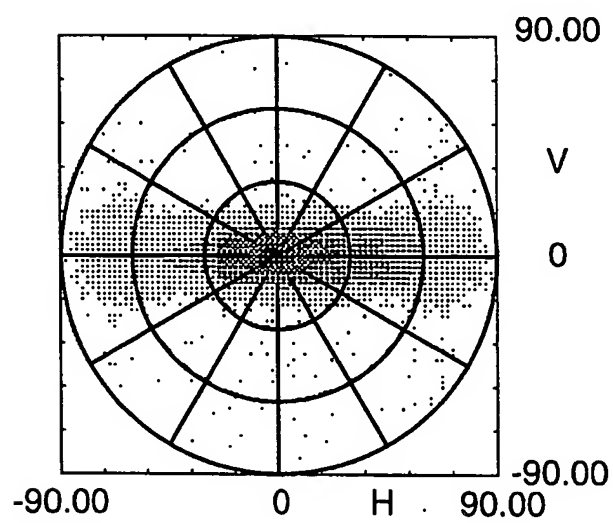


Fig. 1

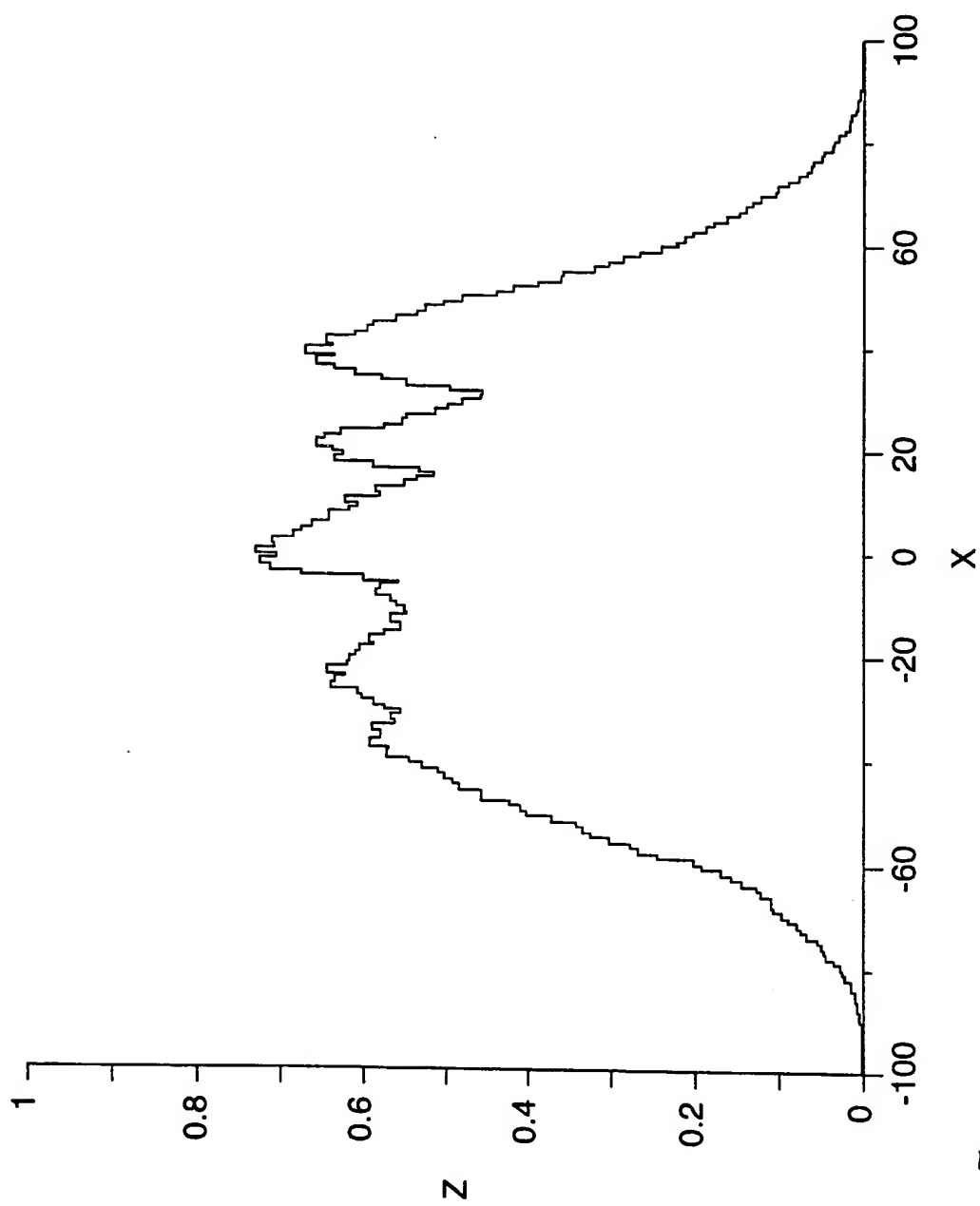




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*Fig.4**Fig.6*

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*Fig. 5*

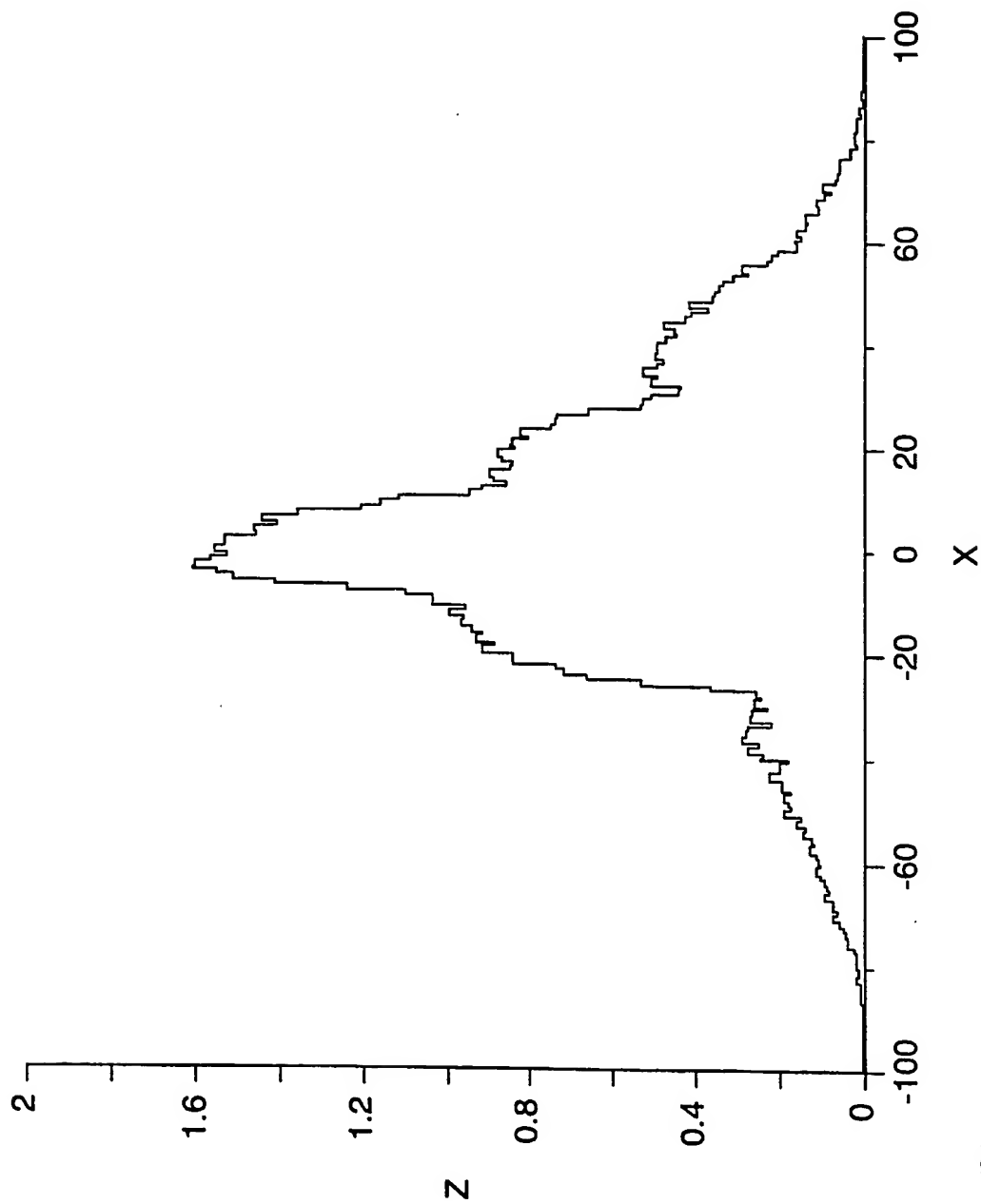


Fig. 7



# INTERNATIONAL SEARCH REPORT

International Application No

PCT/US 99/20474

## A. CLASSIFICATION OF SUBJECT MATTER

IPC 7 F21V8/00

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 7 F21V

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 0 594 089 A (MINNESOTA MINING&MANUFACTURING) 27 April 1994 (1994-04-27) cited in the application the whole document	1-3, 5, 6, 8-10, 12-15, 18
Y	---	4, 7-12, 14-18
Y	WO 96 17207 A (PRECISION LAMP) 6 June 1996 (1996-06-06) abstract; figures 2, 9, 10	4, 7
Y	US 4 765 701 A (L.W.CHESLAK) 23 August 1988 (1988-08-23) column 6; figures 1-5 --- -/-	7, 16

☒ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

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Date of the actual completion of the international search

14 January 2000

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## C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

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X	F.M.LAWSON ET AL.: "FIBER-OPTIC LAMP" IBM TECHNICAL DISCLOSURE BULLETIN, vol. 24, no. 3, 3 August 1981 (1981-08-03), pages 1347-1348, XP002127584 NEW-YORK the whole document -----	1,6,13, 16

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information on patent family members

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